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Revegetating Russian Knapweed (*Acroptilon repens*) and Green Rabbitbrush (*Ericameria teretifolia*) Infested Rangeland in a Single Entry

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The objective of this study was to test the potential for using a single-entry procedure to revegetate Russian knapweed– and green rabbitbrush–infested rangeland. I hypothesized that simultaneously applying an herbicide and seeding in the fall would produce the highest establishment and growth of desired species. For Russian knapweed, treatments included three seeding rates (zero, low, and high) and two herbicides (with and without clopyralid plus 2,4-D) applied in either the spring (2003) or fall (2004). The seed mixture included pubescent wheatgrass, Siberian wheatgrass, and alfalfa. Grasses were seeded on October 21, 2003 (fall dormant), and April 5, 2004 (spring), using a no-till rangeland drill. The seeding rates consisted of 3.4, 6.8, and 9.3 (low) or 5.0, 9.0, and 12.3 (high) kg ha^{-1} of alfalfa, Siberian wheatgrass, and pubescent wheatgrass, respectively. For green rabbitbrush, treatments included two seeding levels (13.5 kg ha^{-1} of Siberian wheatgrass and not seeded) and three herbicides (clopyralid, dicamba, and 2,4-D) and a control applied in July. Clopyralid plus 2,4-D (0.21 plus 1.12 kg ha^{-1}) and dicamba at 2.1 kg ha^{-1} gave 61 and 66% control of Russian knapweed and green rabbitbrush, respectively. Herbicides interacted with seeding to provide the highest density of seeded species on the Russian knapweed site. These data support the hypothesis that simultaneously applying an herbicide and seeding in the fall would produce the highest establishment and growth of desired species. Conversely, only seeding affected Siberian wheatgrass establishment on the rabbitbrush sites. It may be reasonable to seed Siberian wheatgrass without controlling rabbitbrush if forage production is the primary objective.

Nomenclature: Clopyralid; 2,4-D; green rabbitbrush, *Ericameria teretifolia* (Dur. & Hilg.) Jepson ERITE; Russian knapweed, *Acroptilon repens* (L.) DC. ACRRE; alfalfa, *Medicago sativa* L.; pubescent wheatgrass, *Agropyron intermedium* var. *trichophorum* (Link) Halac; Siberian wheatgrass, *Agropyron fragile* (Roth) Candargy.

Key words: Range reseeding; rehabilitation; invasive weeds management.

Indigenous weeds and nonindigenous invasive plants have many negative impacts on rangelands throughout the world. Weeds and invasive plants can displace desirable species, alter ecological processes, reduce wildlife habitat, degrade riparian systems, and decrease productivity (DiTomaso 2000; Miller et al. 2005; Randall 1996). Invasive plants are estimated to infest about 100 million ha in the United States (National Invasive Species Council 2001). Experts recognize that invasive species are the second most important threat to biodiversity after habitat destruction (Pimm and Gilpin 1989; Whittenberg and Cock 2001). Furthermore, Wilcove et al. (1998) estimated that invasive species have contributed to the placement of 35 to 46% of the plants and animals on the Federal Endangered Species List. In 1994, the impacts of invasive plant species in United States were estimated to be $13 billion per year (Westbrooks 1998).

Revegetation is often considered a critical portion of integrated weed management (Jacobs et al. 1999). On rangeland devoid of competitive desirable species, weed control is usually short-term because desirable species are not available to occupy the niches opened by herbicide application (Laufenberg et al. 2005; Sheley et al. 2005). With respect to broadleaved weeds, Pokorny et al. (2005) found forbs that have similar morphological and phenological growth characteristics as the weeds of concern are central to minimizing reinvasion. Thus, revegetating desired species that maximize niche occupation is a major objective in invasive weed management. Unfortunately, establishing desired species in weed-dominated areas has proven very difficult. Although failures are rarely documented in the literature, it is possible, and even likely, that failures in revegetation are the norm. Consequently, managers are reluctant to attempt revegetation because of the high risk and costs associated with multiple failures.

To enhance the success of establishing desired species and reduce the costs associated with a multi-attempt, multi-entry approach, Sheley et al. (2001) developed a single-entry revegetation strategy. In that study, simultaneously applying picloram in late fall during a fall-dormant seeding of various wheatgrasses (*Agropyron* spp.) maximized seedling establishment in spotted knapweed [*Centaurea stoebe* L. ssp. *micranthos* (Gugler) Hayek]–infested rangeland. This single-entry approach has provided managers with a cost-effective and reliable revegetation strategy for spotted knapweed–infested rangeland. However, this single-entry approach has not been tested for use in other weed situations.

The overall objective of this study was to test the potential for using the single-entry revegetation approach developed for spotted knapweed on two other weed species: Russian knapweed, an aggressive, rhizomatous weed nonindigenous to North America, and green rabbitbrush, an indigenous weedy shrub. I hypothesized that simultaneously applying an herbicide and seeding in the fall would produce the highest establishment and growth of desired species.

Materials and Methods

Russian Knapweed. *Study Site*. This study was conducted 11.3 km west of Burns in southeast Oregon (43°36′N, 118°54′W) from 2003 to 2006. Elevation at the knapweed site is 1,259 m, and the long-term (25 yr) mean annual precipitation is 275 mm. During the study period, mean annual temperature and mean annual precipitation ranged from 7.06 to 8.27 C and 248 to 416 mm, respectively. The soil at the knapweed site is Poujade fine loam (fine-loamy, mixed, frigid Durinodic Xeric Natrargids). Characteristic vegetation of this soil includes black greasewood [*Sarcobatus vermiculatus* (Hook.) Torr.] and basin big sagebrush (*Artemi-*

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sia tridentata Nutt. ssp. *tridentata*) in the shrub layer with basin wildrye [*Leymus cinereus* (Scribn. & Merr.) A. Löve], inland saltgrass [*Distichlis spicata* (L.) Greene], and occasionally, sandbergs bluegrass (*Poa secunda* J. Pres.). At the beginning of the study, this site was completely dominated by Russian knapweed.

Procedures and Experimental Design. Treatments included three seeding rates and two herbicides (with and without) applied in either the spring (2003) or fall (2004). This 3 by 2 by 2 experiment was replicated four times in a randomized complete-block design. The seed mixture included 'Luna' pubescent wheatgrass, 'Vavilov' Siberian wheatgrass, and 'Ladak' alfalfa. Grasses were seeded on October 21, 2003 (fall dormant) and April 5, 2004 (spring) using a no-till rangeland drill. The low seeding rate consisted of 3.4, 6.8, and 9.3 kg ha^{-1} of alfalfa, Siberian wheatgrass, and pubescent wheatgrass, respectively. The high rate seeding rate was 5.0, 9.0, and 12.3 kg ha^{-1} of alfalfa, Siberian wheatgrass, and pubescent wheatgrass, respectively. Grasses were seeded to a depth of 4 mm, and alfalfa seeds were allowed to flow onto the soil surface behind the disk but before being packed with a pipe pulled directly over the drill row. Plots were 5 m wide and 10 m long.

In addition to a nonseeded control, the herbicide treatment was clopyralid plus 2,4-D applied at 0.21 kg ai ha^{-1} plus 1.12 kg ai ha^{-1}. Herbicides were applied in the same process as seeding using a front-mounted spray applicator calibrated to deliver a total volume of 310 L ha^{-1}.

Green Rabbitbrush. *Study Site*. This study was conducted on two sites located about 11 km southwest of French Glen in southeast Oregon (42°43′48″N, 119°5′24″W) between 2004 and 2006. Elevation at the French Glen site is 1,392 m, and the long-term (57 yr) mean annual precipitation is 299 mm. The French Glen soil is an Enko coarse loam (course-loamy, mixed, mesic Durinodic Xeric Haplocambids). Study sites differed because site 1 had been brushbeat in prior years, whereas site 2 had been burned in a prior year. Characteristic vegetation consisted of basin big sagebrush in the shrub layer growing in association with Thurber's needlegrass [*Achnatherum thurberianum* (Piper) Barkworth], bottlebrush squirreltail [*Elymus elymoides* (Raf.) Swezey ssp. *elymoides*], and Indian ricegrass [*Achnatherum hymenoides* (Roemer & J.A. Schultes) Barkworth]. At the beginning of this study, green rabbitbrush dominated both sites with only an occasional (1% cover) sagebrush plant. At both sites, crested wheatgrass was present but in very low abundance ($<$ 0.1 plant m^{-2}).

Procedures and Experimental Design. Treatments included two seeding levels (seeded and not seeded) and three herbicides or herbicide combinations and a control. Each herbicide or herbicide combination was applied alone and in combination with seeding in July of 2004. Seeding was also conducted without an herbicide. In plots that included seeding, Siberian wheatgrass was no-till drilled at 13.5 kg ha^{-1} using the same rangeland drill and sprayer as above. Herbicides consisted of 2,4-D ester applied at 2.1 kg ha^{-1}, dicamba at 2.1 kg ai ha^{-1}, or clopyralid at 0.42 kg ha^{-1}. Herbicides were applied in the same process as seeding using a front-mounted spray applicators calibrated to deliver a total volume of 310 L ha^{-1}. Plots were 5 by 10 m.

Sampling. Each experiment was sampled at peak standing crop (July) in 2005 and 2006. Density of the seeded species and Russian knapweed was determined by counting the number of plants in three randomly placed 20 by 50-cm frames in each plot. Biomass was determined by clipping plants to ground level. Plants were separated by species, dried (60 C, 48 h), and weighed. In 2005, cover of rabbitbrush was estimated visually for the entire plot, but density was not estimated that year. In 2006, cover and density of this species were measured along three randomly located 10-m transects in each plot using the line–intercept method.

Analysis. *Russian Knapweed*. Initially, data were pooled and tested for homogeneity of variances. This test indicated that data met the assumption for ANOVA. ANOVA was used to determine the effects of seeding rate, herbicide application, and their interaction on the density and biomass of Russian knapweed and the density and biomass of each seeded species. Data were analyzed as a split-split plot in time, which is a repeated measure when 2 yr and two seasons are involved (Peterson 1985). The model included season, year, seeding rate, herbicide, and their factorial combinations. Year, and interactions including year, were tested using the replication by season by seeding rate by herbicide interaction as the error term. Season, and interactions including season, were tested using replication by year by seeding rate by herbicide interaction as the error term. Other main effects and interactions were tested using the error mean square from the overall model. ANOVA P values from *F* tests are presented, and individual means were compared using an LSD test at the 5% level of confidence when P values were significant at the 5% level (Peterson 1985). Data presented in Figures 1–5 are averaged over factors that were not significant and did not interact.

Green Rabbitbrush. After meeting the assumption of homogeneity of variance, data were analyzed to determine the effects of seeding combined with each herbicide on cheatgrass, and crested wheatgrass density and biomass. Data were analyzed as a split plot in time with an incomplete factorial arrangement. The model included year, seeding alone, and combinations of each herbicide and seeding. Year, and interactions including year, were tested using the replication by seeding by herbicide interaction as the error term. Other main effects and interactions were tested using the error mean square from the overall model. Treatment effects on rabbitbrush cover and density were tested using same procedures as described above. The exceptions were that year effect on brush density and cover was not compared because density was not collected in 2005 and cover was collected using two differing techniques each year. ANOVA P values from *F* tests are presented, and individual means were compared using an LSD test at the 5% level of confidence when P values were significant at the 5% level (Peterson 1985).

Results

Russian Knapweed Study. Russian knapweed density was reduced from 125 to about 100 plants m^{-2} (SE = 10.0) by

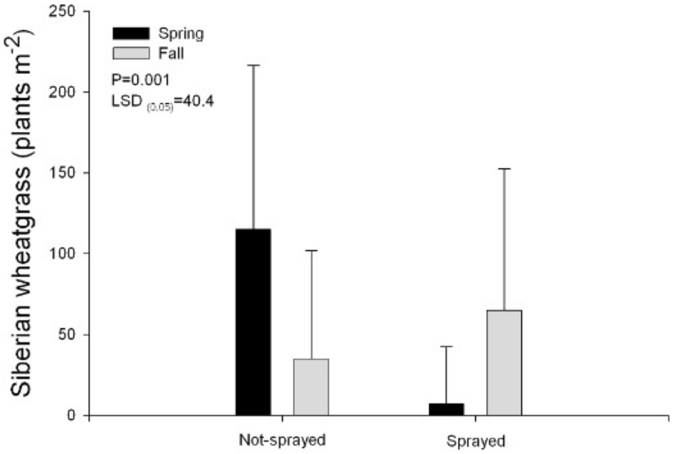

Figure 1. Effects of clopyralid plus 2,4-D (sprayed) and season of spraying and seeding on Siberian wheatgrass density. Data are averaged over factors that were not significant and did not interact.

clopyralid plus 2,4-D (P = 0.01). By 2006, Russian knapweed biomass was reduced from 124 (SE = 27.8) to 48 (SE = 4.5: P = 0.03) g m^{-2} regardless of season of application. No effects of seeding on Russian knapweed were detected at $P \leq 0.05$.

Siberian Wheatgrass. In 2005, the mean density of Siberian wheatgrass was 72 plants m^{-2} (SE = 18.1), and its density had increased to 154 plants m^{-2} (SE = 30.8; P = 0.04;) in 2006. In addition, increasing the seeding rate from low to high increased Siberian wheatgrass density from 129 (SE = 32.2) to 154 (SE = 24.6; P = 0.002) plants m^{-2}.

The influence of clopyralid on Siberian wheatgrass density depended upon the season in which the treatments were applied (Figure 1). Across seeding rates, seeding in the spring without applying the herbicides produced the highest density of Siberian wheatgrass. Applying clopyralid plus 2,4-D reduced Siberian wheatgrass density to almost zero when applied in the spring. Combining the herbicides with a fall seeding produced about one-third the density of Siberian wheatgrass than seeding in the spring without applying the chemicals. Siberian wheatgrass biomass was 21.3 g m^{-2} (SE = 7.9) where plots were not sprayed with the herbicide, and application of the chemicals increased it biomass (P = 0.04) to 63.2 g m^{-2} (SE = 33.6).

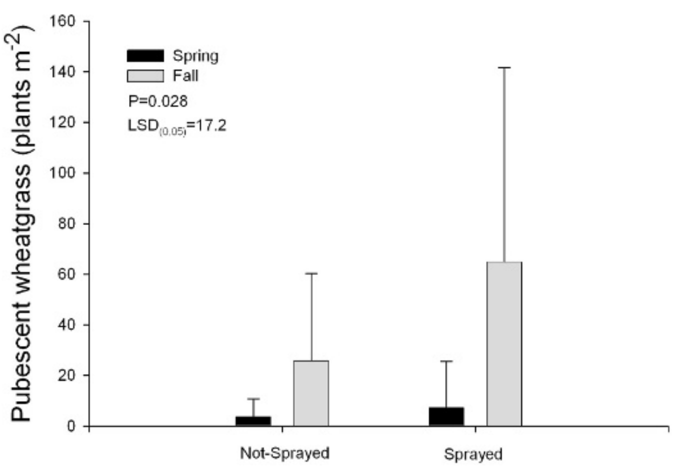

Figure 2. Effects of clopyralid plus 2,4-D (sprayed) and season of spraying and seeding on intermediate wheatgrass density. Data are averaged over factors that were not significant and did not interact.

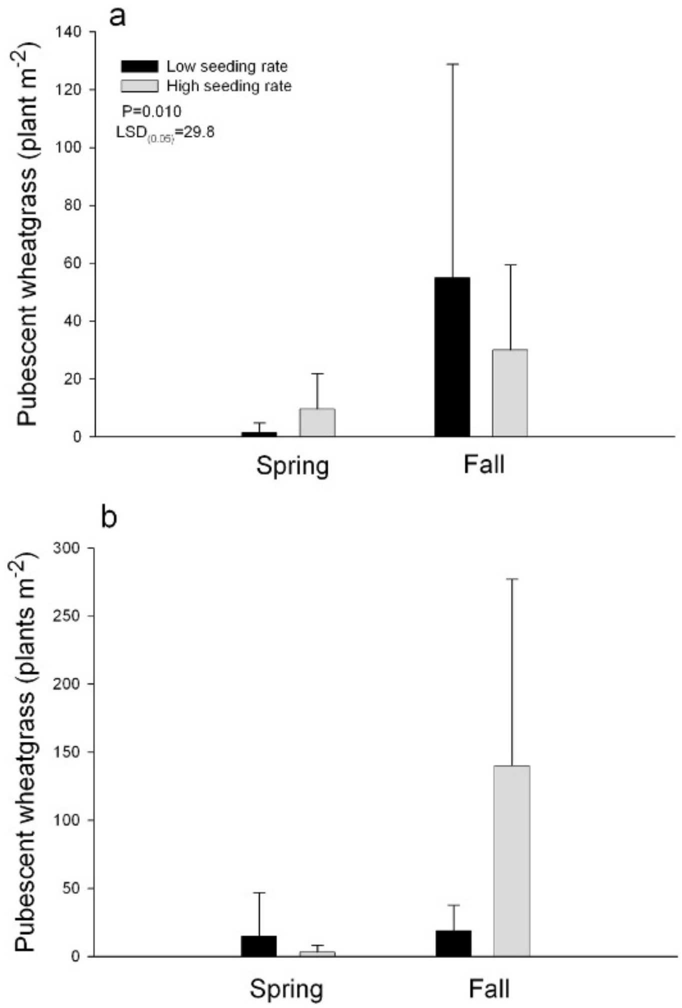

Figure 3. Effects of seeding rate and season of spraying and seeding on pubescent wheatgrass density in (a) 2005 and (b) 2006. Data are averaged over factors that were not significant and did not interact.

Pubescent Wheatgrass. Across seeding rates, seeding in the fall produced about three times higher density of pubescent wheatgrass than seeding in the spring (Figure 2). Applying clopyralid plus 2,4-D in the fall produced the highest density of pubescent wheatgrass, which was about 70 plants m^{-2}.

The effects of seeding rate on pubescent wheatgrass depended upon the year after treatments were applied (Figure 3). In 2005, seeding at the low rate in the fall produced higher densities of pubescent wheatgrass than seeding in the spring or seeding at the high rate in the fall. By 2006, seeding at the high rate in the fall produced the highest pubescent wheatgrass density, which was about six times higher than any other rate by season combination.

The effect of clopyralid plus 2,4-D on pubescent wheatgrass biomass depended on the rate of seeding (Figure 4). At the low seeding rate, no establishment occurred in plots that were not simultaneously sprayed with herbicides. In addition, applying the herbicides at the lowest seeding rate produced the highest biomass of pubescent wheatgrass.

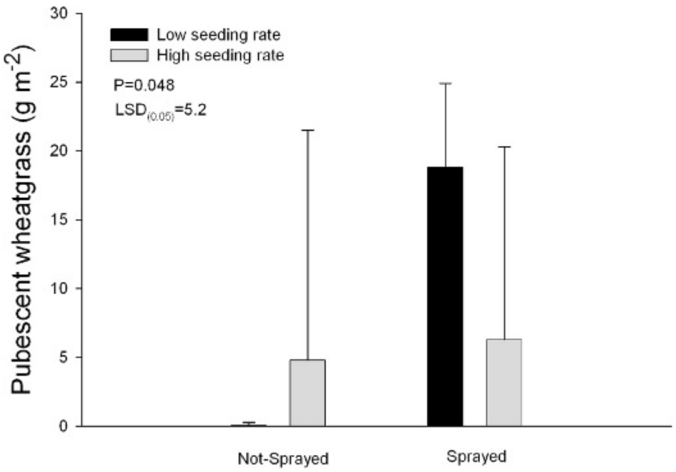

Figure 4. Effects of clopyralid plus 2,4-D (sprayed) and seeding rate on pubescent wheatgrass biomass. Data are averaged over factors that were not significant and did not interact.

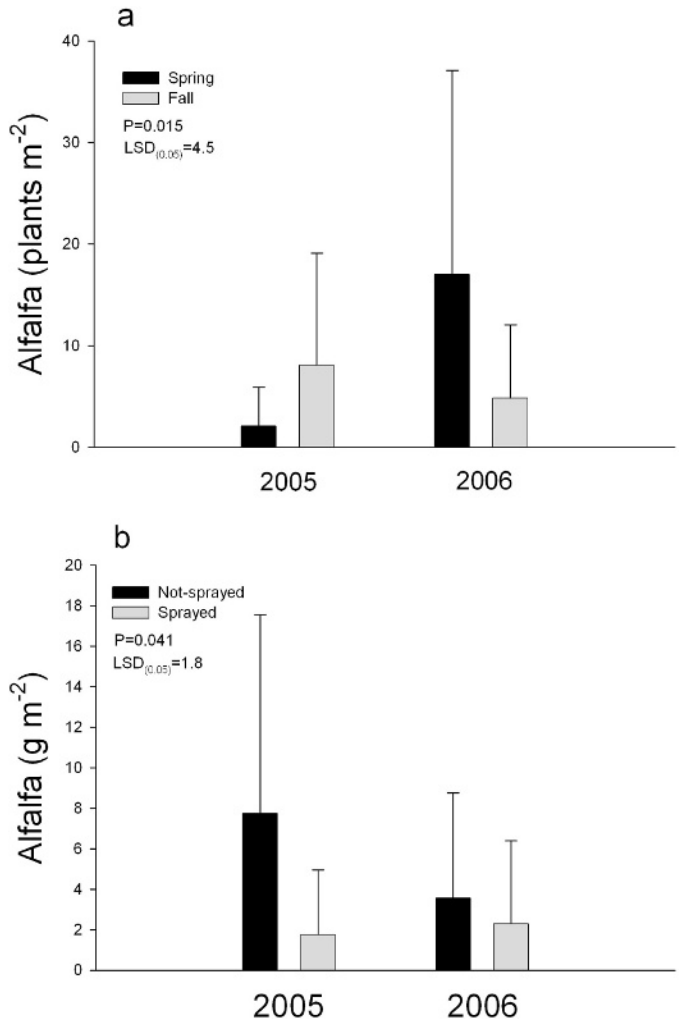

Figure 5. (a) Effects of season of spraying and seeding on alfalfa density in 2005 and 2006. (b) Effects of clopyralid plus 2,4-D (sprayed) on alfalfa biomass. Data are averaged over factors that were not significant and did not interact.

Alfalfa. The density of alfalfa depended upon the season of treatment application and year (Figure 5a). In 2005, plots seeded in the fall had about 8 alfalfa plants m^{-2}, which was about five more than those seeded in the spring. In 2006, plots seeded in the spring had the highest density of alfalfa. The interaction between herbicides and year determined alfalfa biomass (Figure 5b). Alfalfa biomass was highest (7.5 g m^{-2}) in 2005 where no herbicides were applied, which was over twice that produced by any other treatment combination.

Green Rabbitbrush Study. *Undesirable species*. In 2005, rabbitbrush cover differed between sites ($P = 0.03$). Site 1 had 7.3% (SE = 2.4) cover of rabbitbrush, whereas the other had about 14.6% (SE = 2.4) cover of rabbitbrush, regardless of treatments. By 2006, each herbicide reduced rabbitbrush below that of the control (Figure 6). Dicamba produced the lowest rabbitbrush percentage of cover that year.

Cheatgrass was unaffected by any treatment in 2005 ($P > 0.05$). In 2006, cheatgrass density was affected by herbicides ($P = 0.001$) and seeding ($P = 0.004$). The untreated control plots, plots treated with 2,4-D, and those treated with clopyralid had 199, 279, and 297 cheatgrass plants m^{-2} (SE = 33; LSD = 112), respectively. Dicamba increased cheatgrass density to 382 plants m^{-2} that year. Seeded plots had about 241 cheatgrass plants m^{-2}, whereas those plots not seeded had an average of 338 cheatgrass plants m^{-2} in 2006.

Crested Wheatgrass. In 2005, crested wheatgrass density (9 vs. 28 plants m^{-2}; SE = 4.5, $P = 0.003$) and biomass (4 vs. 13 g m^{-2}; SE = 2.6, $P = 0.01$) was higher on one site that was not brushbeat before this study. In 2006, the effects of seeding crested wheatgrass on its density also depended on site (Figure 7). At both sites, seeding increased the number of tillers of crested wheatgrass, but the increase was higher at the site that was brushbeat. Across all treatments, the biomass of crested wheatgrass was 13 g m^{-2} (SE = 2.0) in seeded plots and 5 g m^{-2} (SE = 2.1) in plots not seeded ($P = 0.01$).

Discussion

Although revegetation of invasive weed infested rangeland has been shown to minimize reinvasion (Carpinelli et al. 2004; Sheley and Carpinelli 2006), managers are reluctant to attempt it because the costly multi-attempt, multiple-entry approaches used often fail to establish an adequate stand. Single-entry revegetation that simultaneously applies herbicides, creates a furrow, places seeds into the furrow, and covers the seeds with soil has been useful for revegetating spotted knapweed infested rangeland (Sheley et al. 2001). In this study, the single-entry system was effective in revegetating area dominated by either Russian knapweed or green rabbitbrush.

Russian Knapweed. Clopyralid, sometimes with 2,4-D, is the most commonly used herbicide treatment for Russian knapweed (Sheley and Petroff 1999). Whitson et al. (1991) achieved greater than 95% control of Russian knapweed using 0.25 kg ha^{-1} of clopyralid, and Laufenberg et al. (2005) reduced Russian knapweed from 125 to 25 g m^{-2} using relatively low rates of clopyralid (0.08 kg ha^{-1}) plus 2,4-D (0.42 kg ha^{-1}), regardless of timing of application. On the contrary, Benz et al. (1999) found that clopyralid plus 2,4-D

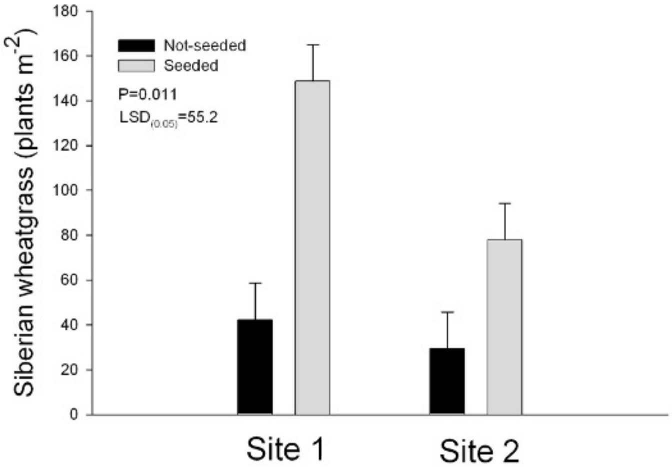

Figure 6. Effects of seeding Siberian wheatgrass on its density.

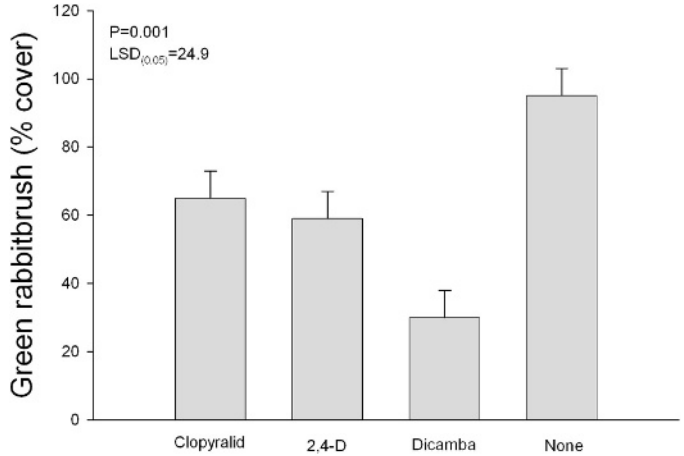

Figure 7. Effects of herbicides on the percent cover of green rabbitbrush.

only provided 7% control applied at rates of 0.3 kg ha^{-1} (clopyralid) and 1.1 kg/ha (2,4-D) in November. I achieved about 61% control across treatments. Apparently, Russian knapweed control using clopyralid and 2,4-D is highly variable, most likely because of its rhizomatous root system, weather condition, and physiological condition of the plants. Although Benz et al. (1999) seeding grasses combined with applying these herbicides increased Russian knapweed control from 7% to between 66 and 93%, seeding did not increase the level of control in this study. I believe that these stands are too early in their establishment to exert much pressure on the weed.

Siberian wheatgrass is a form of crested wheatgrass that has been reported to establish and grow faster in harsher conditions than 'Nordan' and other varieties of this group of grasses (Asay et al. 1995). A study aimed at determining the influence of various rates and times of application on several wheatgrass species show Nordan crested wheatgrass to be very tolerant to higher rates of clopyralid than used in this study (Sheley et al. 2002). Similarly, 2,4-D had no effect on crested wheatgrass (applied before and after germination in either spring or fall conditions) (Klomp and Hull 1968). In this study, the Vavilov form of crested wheatgrass was reduced by a combination of clopyralid plus 2,4-D. In fact, the highest establishment of this grass occurred without herbicide application and, thus, in the presence of Russian knapweed.

Luna pubescent wheatgrass has been identified as a useful grass for seeding into rangeland infested with invasive weeds (Ferrell et al. 1993; Sheley et al. 2001). With this grass, I found evidence that simultaneously applying an herbicide and seeding in the fall would produce the highest establishment of desired species. Luna pubescent wheatgrass density was about six times greater than any other species but only where it was seeded at the highest rate and herbicides were applied. However, this high density resulted in lower biomass of this wheatgrass, most likely because intraspecific interference became intense, similar to that found by for intermediate wheatgrass [*Thinopyrum intermedium* (Host) Barkworth & D.R. Dewey] when seeding high densities with spotted knapweed (Velagala et al. 1997).

Including alfalfa in stands of crested wheatgrass and intermediate wheatgrass substantially improved the resistance of the plant community to invasion by spotted knapweed (Carpinelli et al. 2004). Because alfalfa is susceptible to most broadleaved herbicides (William et al. 2006), I expected that it would not establish well, if at all, where clopyralid plus 2,4-D were applied. Not surprisingly, the highest density of alfalfa occurred in plots that were not sprayed. It was promising that there were 3.5 alfalfa plants m^{-2} in plots that received the herbicides. Establishing and maintaining plants that occupy multiple niches may provide some invasion resistance, even at these low densities (Pokorny et al. 2005).

Green Rabbitbrush. In other studies, 2,4-D, dicamba, and clopyralid have provided 80% or more control of rabbitbrush (Cluff et al. 1983; Mohan 1973; Whisenant 1988). Achieving this level of control requires applying herbicides when plants are actively growing, usually indicated by 6 to 10 cm of new leader growth (Hyder et al. 1958; Mohan 1973). It has also been suggested that soil moisture should be high enough to allow rapid growth (Mohan 1973). In this study, herbicide application and seeding were conducted in July, which appeared late in the growing season for greater than 66% control. Soil moisture conditions were likely lower than that needed for continued active growth by rabbitbrush.

My data did not support the hypothesis that simultaneously applying an herbicide and seeding in the fall would produce the highest establishment and growth of desired species. Seeding alone increased crested wheatgrass, but controlling rabbitbrush did not enhance the establishment of this grass. It is possible that 66% control of rabbitbrush is inadequate to convey a benefit to crested wheatgrass. Among the several studies aimed at controlling rabbitbrush (Cluff et al. 1983; Mohan 1973; Whisenant 1988), only Evans and Young (1975) report an increase in grass biomass. In that case, needle and thread grass accounted for all of the increase, whereas other grasses were unaffected. Frischknecht (1963) compared the effects of removing big sagebrush and rubber rabbitbrush (*Chrysothamnus nauseosus L.*) on grass yields. He found removal of big sagebrush increased grass yield by about 20%, but removal of rabbitbrush had no effect on grasses. It is possible that, like crested wheatgrass, Siberian wheatgrass and rabbitbrush do not compete directly. It may be reasonable to seed crested wheatgrass without controlling rabbitbrush if forage production is the primary objective.

Conclusions

Revegetating invasive plant–dominated rangeland with desired species is central to effective management. However, the current multi-entry, multi-attempt approach is too expensive and the likelihood of failure is high. This study expands the research by Sheley et al. (2001) showing that a single-entry program that simultaneously applies an herbicide with a fall-dormant seeding would enhance desired species establishment on spotted knapweed–infested rangeland by testing the practice on two other weedy species, Russian knapweed and green rabbitbrush. In the case of Russian knapweed, this single-entry approach was effective, but indicated that certain species or varieties may be susceptible to herbicide damage, such as Vavilov Siberian wheatgrass, to certain herbicides when applied simultaneously in the fall. The system also worked well for reseeding green rabbitbrush–infested rangeland, but controlling this weed did not enhance establishment. The single-entry system may provide a more cost-effective and reliable method for revegetating weed-infested rangeland. However, before applying an herbicide, it will be important to know the degree to which the weed actually limits establishment. Choosing the correct herbicide and species for seeding will enhance the likelihood of cost-effective revegetation using this single-entry approach.

Literature Cited

Asay, K.H., D.A. Johnson, K.B. Jensen, N.J. Chatterton, W.H. Horton, W.T. Hansen, and S.A. Young. 1995. Registration of 'Vavilog' Siberian crested wheatgrass. Crop Sci. 35:1510.

Benz, L.J., K.G. Beck, T.D. Whitson, and D.W. Koch. 1999. Reclaiming Russian knapweed infested rangeland. J. Range Manag. 52:351–356.

Carpinelli, M.F., R.L. Sheley, and B.D. Maxwell. 2004. Revegetating weed-infested rangeland with niche-differentiated desirable species. J. Range. Manag. 57:97–105.

Cluff, G.J., B.A. Roundy, R.A. Evans, and J.A. Young. 1983. Herbicidal control of greasewood (*Sarcobatus vermiculatus*) and salt rabbitbrush (*Chrysothamnus nauseosus* ssp. *Consimilis*). Weed Sci. 23:394–401.

DiTomaso, J.M. 2000. Invasive weeds in rangelands: species, impacts, and management. Weed Sci. 48:255–265.

Evans, R.A. and J.A. Young. 1975. Aerial application of 2,4-D plus picloram for green rabbitbrush control. J. Range Manag. 28:315–318.

Ferrell, M.A., T.D. Whitson, D.W. Koch, A.E. Gade, and R.G. Lym. 1993. Integrated control of leafy spurge (*Euphorbia esula*) with Bozoisky Russian wildrye (*Psathyrostachys juncea*) and Luna pubescent wheatgrass (*Agropyron intermedium* var. *trichophorum*). Proc. West. Soc. Weed Sci. 46:36–38.

Frischknecht, N.C. 1963. Contrasting effects of big sagebrush and rubber rabbitbrush on production of crested wheatgrass. J. Range. Manag. 16:70–74.

Hyder, D.N., F.S. Sneva, D.O. Chilcote, and W.R. Furtick. 1958. Chemical control of rabbitbrush with emphasis upon simultaneous control of big sagebrush. Weeds 6:289–297.

Jacobs, J.S., M.F. Carpinelli, and R.L. Sheley. 1999. Revegetating noxious weed-infested rangeland. Page 438 *in* R. Sheley and J. Petroff, eds. Biology and Management of Noxious Rangeland Weeds. Corvallis, OR: Oregon State University Press.

Klomp, G.J. and A.C. Hull, Jr. 1968. Effects of 2,4-D on emergence and seedling growth of range grasses. J. Range Manag. 21:67–70.

Laufenberg, S.M., R.L. Sheley, J.S. Jacobs, and J. Borkowski. 2005. Herbicide effects on density and biomass of Russian knapweed (*Acroptilon repens*) and associated plant species. Weed Technol. 19:62–72.

Miller, R.F., J.D. Bates, T.J. Svejcar, F.B. Pierson, and L.E. Eddleman. 2005. Biology, Ecology, and Management of Western Juniper. Corvallis, OR: Oregon State University, Agricultural Research Service Technical Bulletin 152.

Mohan, J.M. 1973. 14 years of rabbitbrush control in central Oregon. J. Range Manag. 26:448–451.

National Invasive Species Council. 2001. Meeting the Invasive Species Challenge: National Invasive Species Management Plan. Beltsville, MD: National Invasive Species Council. 80 p.

Peterson, R.G. 1985. Design and analysis of experiments. New York: Marcel Dekker. 272 p.

Pimm, S. and M. Gilpin. 1989. Theoretical issues in conservation biology. Pages 287–305 *in* J. Roughgarden, R. May, and S. Levey, eds. Perspectives in Ecological Theory. Princeton, NJ: Princeton University Press.

Pokorny, M.L., R.L. Sheley, C.A. Zabinski, R.E. Engel, T.J. Svejcar, and J.J. Borkowski. 2005. Plant functional group diversity as a mechanism for invasion resistance. Restor. Ecol. 13:448–459.

Randall, J. 1996. Weed control for the preservation of biological diversity. Weed Technol. 10:370–383.

Sheley, R.L. and M.F. Carpinelli. 2006. Creating weed-resistant plant communities using niche-differentiated nonnative species. Range. Ecol. Manag. 58:480–488.

Sheley, R.L., J.S. Jacobs, and D.E. Lucas. 2001. Revegetating spotted knapweed infested rangeland in a single entry. J. Range Manag. 54:144–151.

Sheley, R.L., J.S. Jacobs, and T.J. Svejcar. 2005. Integrating disturbance and colonization during rehabilitation of invasive weed-dominated rangeland. Weed Sci. 53:307–314.

Sheley, R. and J. Petroff. 1999. Biology and management of noxious rangeland weeds. Corvallis, OR: Oregon State University Press. 438 p.

Sheley, R.L., T.D. Whitson, V. Carrithers, J.S. Jacobs, and J. Gehrett. 2002. Weed Technol. 16:645–650.

Velagala, R.P., R.L. Sheley, and J.S. Jacobs. 1997. Influence of density on intermediate wheatgrass and spotted knapweed interference. J. Range Manag. 50:523–529..

Westbrooks, R. 1998. Invasive Plants, Changing the Landscape of America: Fact Book. Washington, D.C.: Federal Interagency Committee for the Management of Noxious and Exotic Weeds. 109 p.

Whisenant, S.G. 1988. Control of threadleaf rubber rabbitbrush with herbicides. J. Range Manag. 41:470–472.

Whitson, T.D., J.L. Baker, R.D. Cunningham, and T.E. Heald. 1991. Control of Russian knapweed with various herbicides applied at three growth stages. Las Cruces, NM: Western Society of Weed Science Research Progress Report. Pp. 88–89.

Whittenberg, R. and M.J. Cock. 2001. Invasive Alien Species: A Toolkit of Best Prevention and Management Practices. Global Invasive Species Prgramme. Wallingford, Oxon, UK: CABI. 228 p.

Wilcove, D.S., D. Rothstein, and J. Dubow. 1998. Quantifying threats to imperiled species in the United States. Bioscience 48:607–615.

William, R., D. Ball, R. Parker, T. Miller, D. Morishita, and P. Hutchinson. 2006. Pacific Northwest 2006 Weed Management Handbook. Corvallis, OR: Oregon State University Extension Special Publication.

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